6.4.6 Landslide Analysis

Landslide analysis is perhaps one of the more difficult types of geotechnical analyses due to the variable size and complexity of landslides. TRB Landslide Investigation & Mitigation provides a basis for analysis techniques and requirements. It is essential that survey information extend beyond the landslide limits to provide detailed analysis. For most Federal Lands Highway projects, the total size of the landslide and costs of correction must be subjectively evaluated in relationship to potential costs of noncorrection before detailed investigations are authorized and initiated.

The factor of safety (FS) for landslide analysis should vary with the type of facility, potential damages, amount and quality of soil strength data and size of the landslide. In addition, the reliability of site-specific rainfall and ground water level should be considered. Generally, a factor of safety in the 1.25 to 2.0 range is used, with 1.3 being most common. Use of low-cost methods (e.g., alignment shifts, grade changes, horizontal drains, rock buttresses and excavation) to remove driving forces should be routinely considered.

Information required from landslide analysis should include the following:

- physical limits and dimensions of the landslide,
- listing of probable causes for landslide,
- magnitude and rate of existing movements, and
- recommendations for corrective actions and evaluation of future risk.

The following provides the basic procedural steps, initial source of reference material and standard forms for a typical landslide investigation:

1. **Initiate Project**. The following applies:

    - Identify available preliminary information (see Exhibit 6.3-A).
    - Identify project related restrictions (e.g., financial, aesthetic, environmental).

2. **Review Available Geotechnical Data**. The following applies:

    - Review all previous geotechnical reports and information for specific project.

    - Review published information (see Exhibit 6.3-C).

    - Identify landslide problem history of the general area, and determine site specific history.

    - Obtain survey information (e.g., contour maps, cross sections and plans).

3. **Plan Field Investigations**. The following applies:

    - Determine drilling requirements (see Exhibit 6.3-E).

    - Review checklists for landslide correction (Form 6.4-U) to identify needed information to be collected.

- Determine preliminary equipment requirements (see Exhibits 6.3-B, 6.3-D, 6.3-F and 6.3-L).
- Identify site access restrictions, and revise equipment requirements accordingly. A site visit may be necessary.
- Develop a Preliminary Boring and Testing Plan (see Form 6.3-B).

4. **Plan and Sampling Testing**. The following applies:
   - Determine sampling and testing requirements (see Exhibits 6.3-E, 6.3-G and 6.3-U).
   - Appraise the need for in-situ testing and long-term monitoring devices.
   - Record field information (Forms 6.3-B, 6.4-C, 6.4-D, 6.4-H and 6.4-K through 6.4-R, as applicable).
5. **Summarize Field Data**. Summarize soil profile information (see Form 6.4-F and Exhibit 6.4-B).
6. **Perform Analysis and Write Report**. The following applies:
   - Review the Landslide Correction Checklist (Form 6.4-U) to ensure all appropriate information is available.
   - Perform appropriate analysis.
   - Write draft report (see Section 6.6).
   - Refer to the General Report Checklist (Form 6.4-G) and the Site Investigation Checklist (Form 6.4-H) to ensure appropriate report content.
   - Finalize report.

6.4.7 Subsurface Drainage

The presence of saturated soils or shallow ground water may produce adverse effects on the construction and maintenance of roadways and embankments. The sources of this subsurface water may be free water penetrating the subsurface due to the force of gravity, capillary water that moves upward through the underlying soil strata as a result of capillary action, or water vapor moving upward through the subgrade soil strata as a result of thermal gradients. In general, these adverse effects of excessive subsurface water cause slope failures including the sloughing and sliding of cut and fill slopes and unsatisfactory pavement performance as manifested in premature rutting, cracking, faulting, increasing roughness and a relatively rapid decrease in the level of serviceability.

Landslide Correction Checklist

Project: ______________________________

Location: ______________________________

Prepared by: ____________________ **Date:** ____________________

Components	Check Appropriate Box		
	Yes	No	Not Applicable
1. Does the report include a site plan and typical cross section showing ground surface conditions both prior to and after failure?			
2. Has a site reconnaissance been conducted to define the limits of the slide improvement?			
3. Are slide limits (including location of ground surface cracks, head scarp and toe bulge) shown on the site plan?			
4. Is past history (movement history, maintenance work and costs and corrective measures taken) of slide are summarized?			
5. Is summary given of results of size investigation, field and lab testing and stability analyses, including cause(s) of the slide?			
6. Is as-built cross section (used for slide stability analysis) included and does cross section show major soil and rock layers and water table location as determined from drilling and sampling?			
7. Is location of slide failure plane (determined from slope indicators and/or drilling) shown on the slide cross section?			
8. Are soil strength values, soil unit weights, and water table elevation(s) (used in the design stability analyses) shown on the slide cross section?			
9. For existing active slide, was soil strength along slide failure plane backfigured using a safety factor equal to 1.0 at time of failure?			
10. Is the following included for each proposed correction alternative:			
a. Cross section of proposed alternative?			
b. Estimated safety factor?			
c. Estimated cost?			
d. Advantages and disadvantages?			

Form 6.4-U SAMPLE OF LANDSLIDE CORRECTION CHECKLIST

Landslide Correction Checklist

Project: ____________________

Location: ____________________

Prepared by: ____________________ **Date:** ____________________

Components (continued)	Check Appropriate Box		
	Yes	No	Not Applicable
11. Is recommended correction alternative given?			
12. Does proposed correction alternative provide a minimum FS = 1.25?			
13. Have the most feasible and cost-effective correction alternatives been considered for the particular slide problem? (typical correction methods include buttress, shear key, rebuild slope, surface drainage, subsurface drainage - interceptor drain trenches or horizontal drains - and retaining structures).			
14. If horizontal drains are proposed as part of slide correction, has subsurface investigation located definite water bearing strata that can be tapped with horizontal drains?			
15. If a toe counterberm is proposed to stabilize an active slide, has field investigation confirmed that the toe of the existing slide does not extend beyond the toe of the proposed counterberm?			
16. Construction considerations:			
a. Where proposed correction will require excavation into the toe of an active slide (e.g., for buttress or shear key) has the construction backslope FS been determined?			
b. Has seasonal fluctuation of groundwater table been determined and was highest water level used in computing open excavation backslope FS?			
c. If open excavation FS is near 1.0, has excavation stage construction been proposed?			
d. Should slide repair work only be allowed during driest period or the year?			
e. Should stability of excavation backslope be monitored?			
17. Are recommended contract specifications provided?			

Comments ____________________

____

Form 6.4-U SAMPLE OF LANDSLIDE CORRECTION CHECKLIST
(Continued)

This damage may be caused in various ways, including the following:

1. **Weakening**. When a roadbed is wholly or partly saturated, the application of dynamic loadings causes increased pore pressures and these reduce the internal friction and lower resistance to shearing action.

2. **Buoyancy**. The buoyant effect of the water reduces the weight of the particles and correspondingly lowers the friction between them.

3. **Expansion**. The volume of some soils is greatly increased by added water, causing differential heaving and weakening of the pavement structure.

4. **Frost Heave**. Freeze-thaw activity related to water in or under a pavement structure is the most common cause of volume changes leading to pavement break-up and potholes.

Prevention of subsurface water problems in highway engineering may be accomplished by either selective highway location, replacement of poor soils and the use of select, free draining, granular subbase materials or by using subsurface drainage systems. This Section will only discuss design guidance for subsurface drainage systems. The functions of subsurface drainage are to reduce the previously mentioned adverse effects on roadways. These functions are more specifically stated in terms of the following requirements:

- to draw-down or lower a highway water table in the area of a highway, parking lot or other type of transportation improvement project;
- to eliminate active springs or seeps beneath the pavement by intercepting the seepage above an impervious boundary;
- to drain surface water infiltrating into the structural section by the following:
    + through a pervious pavement;
    + through cracks, joints or other breaks in the continuity of the pavement and shoulder surfaces;
    + from an improperly-drained median area; or
    + from side ditches; and
- to collect discharge from other drainage systems.

In order to design a reliable, economic and adequate subsurface drain, it is desirable to collect the following information:

- determine, during the preliminary soil survey, the location of all seepage areas that may cause water to enter the structural elements of the pavement;
- determine the maximum rate of flow of water that may enter the structural section from any seepage and infiltration;

- find the location of a source of aggregate suitable for filter material to prevent clogging of drains by water-borne soil or determine the suitability of using a filter fabric;
- determine source of aggregate which, if needed, may be used as drainage blanket to remove the water from beneath the pavement; and
- obtain and evaluate climatic data with respect to frost heaving.

The most common way of identifying subdrainage systems is in terms of their location and geometry. The most familiar classifications of subsurface drainage systems include underdrains, horizontal drains, drainage blankets and wells. The following applies:

1. **Underdrains**. These subsurface drains are categorized as longitudinal drains if they are located parallel to the roadway centerline (both in the horizontal and vertical alignment) and as transverse drains if they run beneath the roadway either at right angles to the roadway centerline or skewed in the so-called "herringbone" pattern. These drains are located not only at the edge of or under the pavement, but may also act as interceptor drains in wet cut slopes. Typically, these drains involve a trench of substantial depth, a collector pipe, free draining aggregate and a protective filter fabric of some kind.

   The function of fabrics as filters is to allow removal of ground water without the build-up of excessive seepage forces or water pressures. The fabric must also prevent piping or subsurface erosion of the soil. In these applications, water flows across the filter into a water-conducting medium, which is usually a trench filled with a free draining aggregate and a slotted or perforated pipe that quickly removes the water. Geotechnical filter fabrics are manufactured from a number of different materials, including polypropylene, polyester, nylon, polyethylene and polyvinylidene chloride.

   For details concerning specifications for various kinds of underdrain pipe, free draining aggregate and filter fabrics, refer to the references in Section 6.2.

   In lieu of pipe underdrains, the use of prefabricated drainage systems (geocomposite drains) for subsurface drainage is increasing rapidly. Variables that should be considered in the design of a geocomposite drain application are drain orientation, in-situ stress, temperature, hydraulic conditions, potential for clogging, permeability and chemical resistance.

   Depending on the source of subsurface water and the function of the drain, less sophisticated underdrains may be used. These may include "french drains," consisting of a shallow trench filled with open graded aggregate or a deep trench drain with filter fabric enveloping an open graded aggregate. Exhibits 6.4-J through 6.4-N show various underdrain details. These drains perform the basic requirement of carrying off all water entering the system by using a protective filter medium to prevent clogging of the drain.

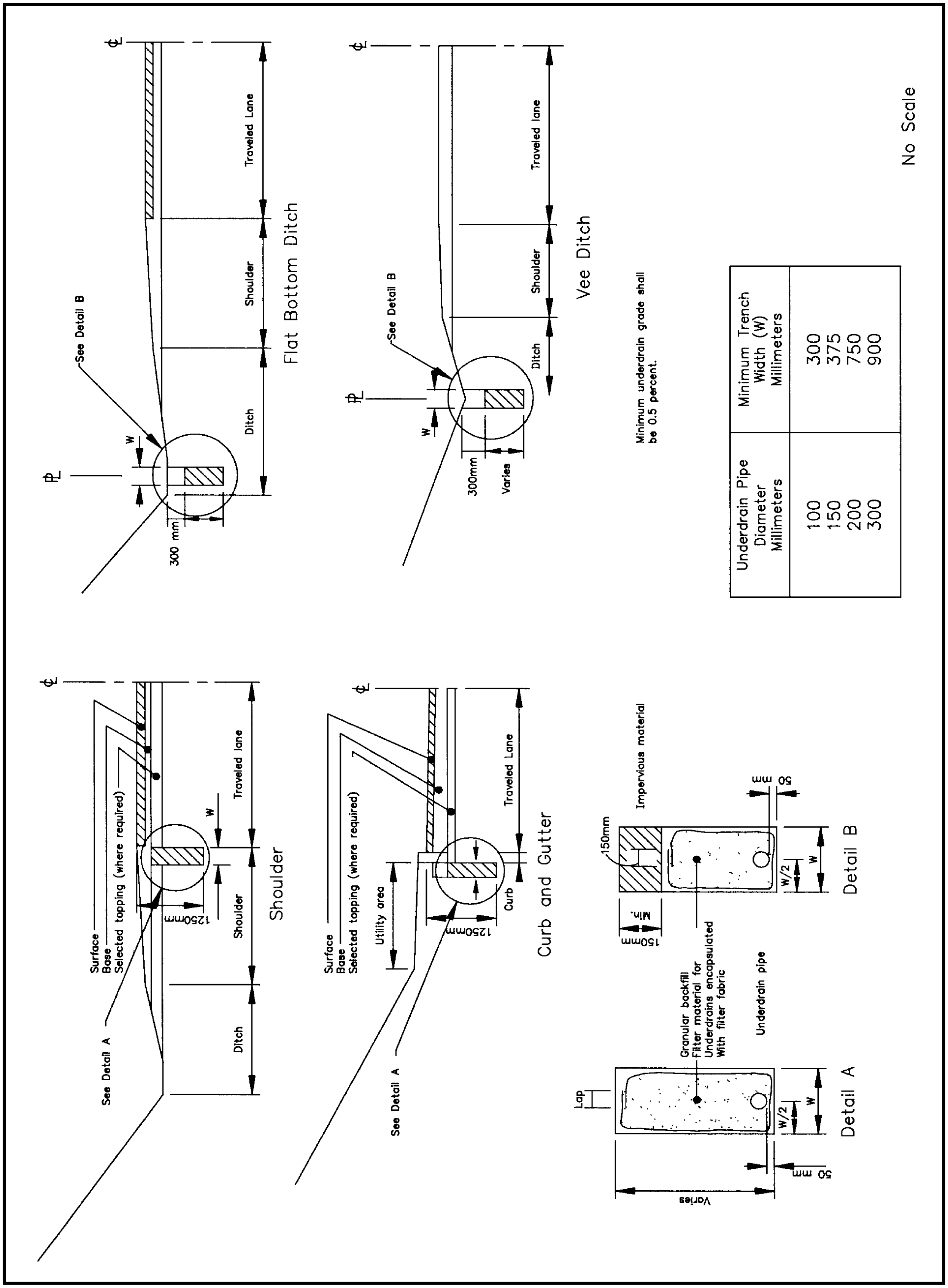
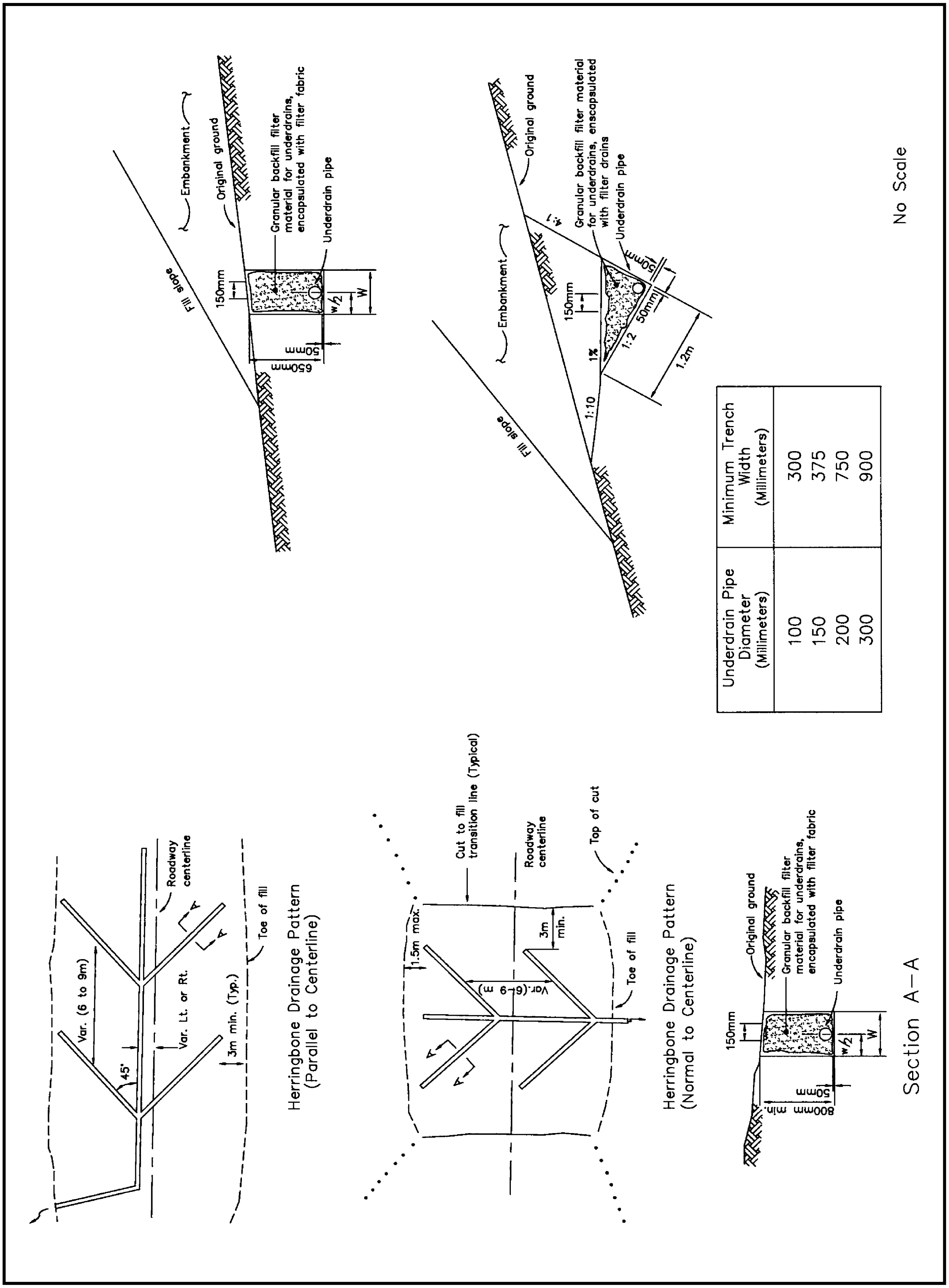


Exhibit 6.4-J TYPICAL UNDERDRAIN INSTALLATION FOR ROADBEDS AND DITCHES (Metric)

To Be Provided

Exhibit 6.4-J TYPICAL UNDERDRAIN INSTALLATION FOR ROADBEDS AND DITCHES (US Customary)



Underdrain Pipe Diameter (Milimeters)	Minimum Trench Width (Millimeters)
100	300
150	375
200	750
300	900

Exhibit 6.4-K TYPICAL UNDERDRAIN INSTALLATION IN EMBANKMENT AREAS (Metric)

To Be Provided

Exhibit 6.4-K TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED (US Customary)

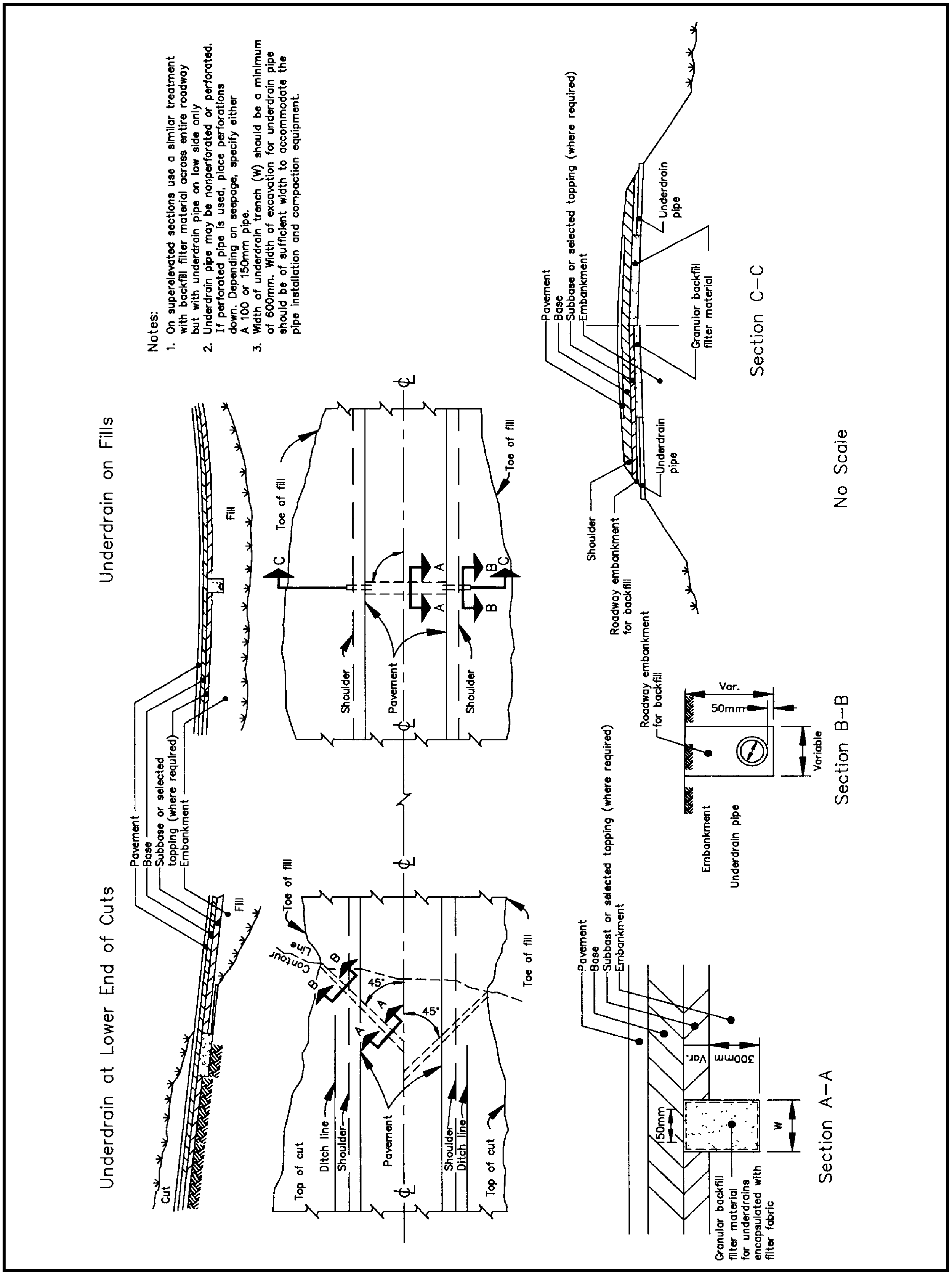


Exhibit 6.4-L TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED (Metric)

To Be Provided

Exhibit 6.4-L TYPICAL UNDERDRAIN INSTALLATION BENEATH THE ROADBED (US Customary)

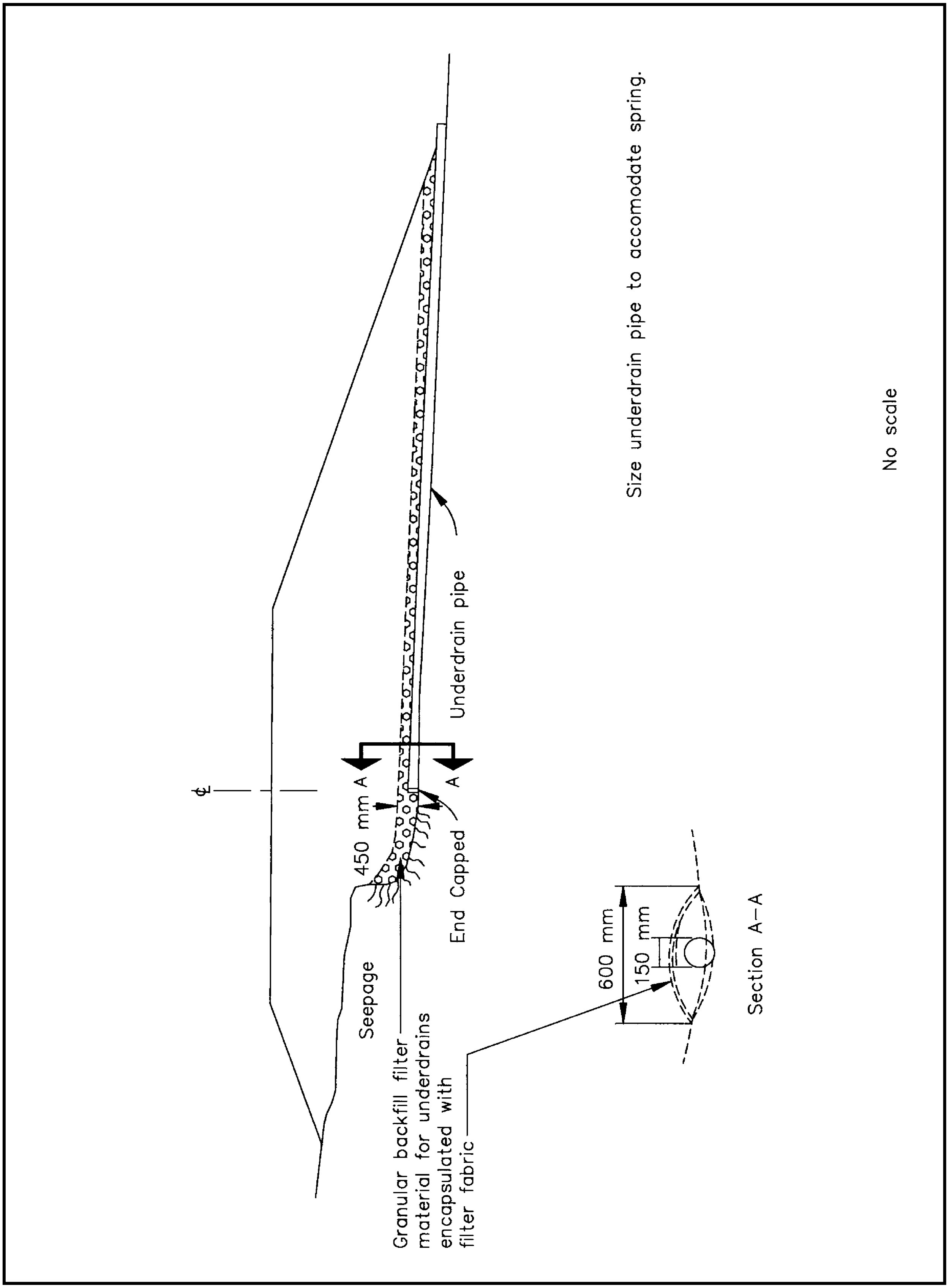
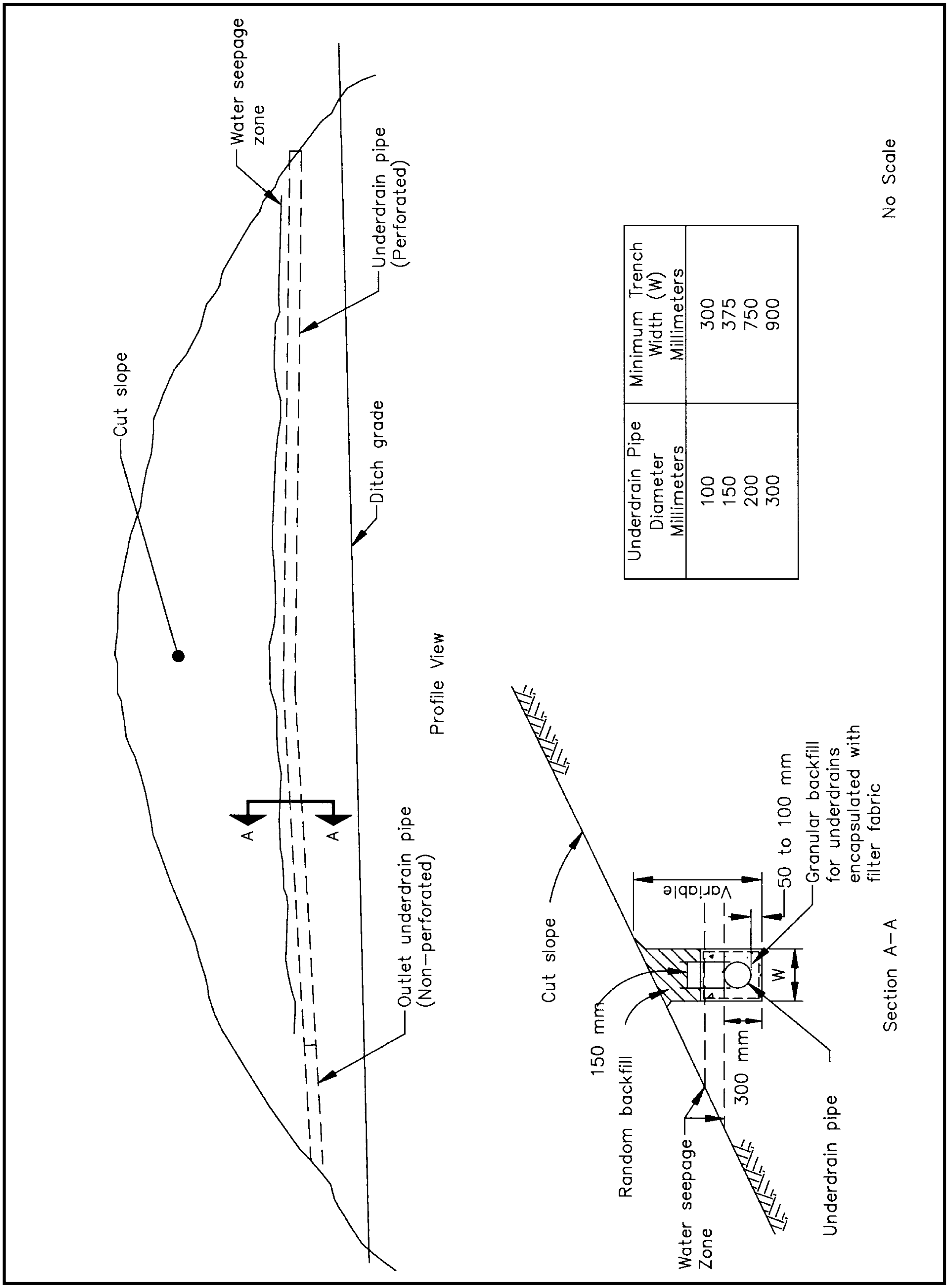


Exhibit 6.4-M TYPICAL UNDERDRAIN INSTALLATION FOR SPRING AREAS (Metric)

To Be Provided

Exhibit 6.4-M TYPICAL UNDERDRAIN INSTALLATION FOR SPRING AREAS (US Customary)



Underdrain Pipe Diameter Millimeters	Minimum Trench Width (W) Millimeters
100	300
150	375
200	750
300	900

Exhibit 6.4-N TYPICAL UNDERDRAIN INSTALLATION FOR BACKSLOPE (Metric)

To Be Provided

Exhibit 6.4-N TYPICAL UNDERDRAIN INSTALLATION FOR BACKSLOPE (US Customary)

2. **Horizontal Drains**. This drainage system consists of horizontal pipes drilled into cut slopes or fill slopes to tap springs and relieve porewater pressures. The skew and inclination of horizontal pipes must be determined on a project-by-project basis, and may have to be adjusted in the field as groundwater is encountered. In ordinary installation, the ends of the perforated, small diameter drain pipes are simply left projecting from the slope and the flow is picked up in drainage ditches.

   In more elaborate installations, however, drainage galleries or tunnels may be required to carry the large flows, and some type of pipe collector system may be used to dispose of the water outside of the roadway limits. The following describes two types of horizontal drains:

3. **Drainage Blankets**. Drainage blankets are applied as a very permeable layer, the length (in the direction of flow) and width of which are large relative to its thickness. Drainage blankets used in conjunction with a longitudinal drain can help to improve the surface stability and, thus, relieve sloughing of cut slopes by preventing the development of a seepage surface. Horizontal drainage blankets can be used beneath or as an integral part of the pavement structure to remove water from infiltration or to remove ground water from both gravity and artisan sources.

   Although relatively pervious granular materials are often used for base and subbase courses, these layers will not function as drainage blankets unless they are specifically designed and constructed to do so. This requires an adequate thickness of material with a very high coefficient of permeability, a positive outlet for the water collected, and in some instances the use of one or more protective filter layers.

4. **Wells**. Wells can be used to control the flow of ground water and relieve pore water pressures in potentially unstable highway slopes. Wells are sometimes used in conjunction with another drainage system to penetrate an impervious layer that prevents or hinders the necessary percolation of subsurface water.

6.5 APPROVALS (RESERVED)

6.6 GEOTECHNICAL REPORTS

The purpose of geotechnical reports is to transmit and document all pertinent geotechnical information in a systematic, concise format with specific design recommendations and alternatives. Pertinent information should consist of site specific physical, environmental and geological data (e.g., field boring logs); station by station field notes; geophysical field data; material properties laboratory test results; discussion of analyses used; listing of all major assumptions and/or data used for analyses; and design and construction recommendations.

Reports are primarily intended for highway designers, but are also made available to project construction personnel and prospective bidders.

6.6.1 Report Structure and Outline

All geotechnical reports should be consistent and organized to follow the same general structure to allow for familiarity by even the occasional reader. The following topic areas should be considered for final reports:

- Introduction,
- Procedures and Results,
- Analysis,
- Discussion,
- Recommendations, and
- Appendices and Attachments (as required).

The introduction section of the geotechnical report should contain information as to the specific location of the project site, the purpose of the report, authorization for the work and any limitations and restrictions that may apply.

Include a review of the project and history of the site as background information when it is relevant to the investigation and/or proposed project.

The procedures and results reported should basically contain information as to what field procedures and tests were performed and what engineering values were determined from the test results. Discuss the existing conditions and pertinent geological setting and features in the report. Use data summaries, tables and charts whenever possible. Document any previous report and/or other specific references used to generalize conditions, estimate engineering parameters and develop recommendations. Include all test data, both field and laboratory, in the report and reference in the appropriate appendices.

The analysis section of a geotechnical report should contain information as to what type of analyses were performed. When appropriate, include the applicable analysis procedures, including limitations and pertinent assumptions.

The discussion section of the report should draw upon all the previously mentioned sections and present the various possible alternative solutions that were considered for each specific feature or project. Include a general discussion that communicates the major advantages and disadvantages of each alternative.

Recommendations in the report should be concise and directed to the preferred alternative. All detailed information necessary to design and construct the recommended alternative should be provided and all reference literature cited. Identify areas where special treatment may be required and make recommendations on the type of treatment or corrective action to be taken.

The appendices of a geotechnical report should contain all detailed laboratory test results, boring logs and field test data used to generate the report. Specific calculations would not normally are not included, but all standard terminology and reference charts used to prepare the report are included.

The following is the generalized geotechnical outline guide:

- Title Page;
- Table of Contents;
- Introduction;
- Procedures and Results;
- Analysis;
- Discussion;
- Recommendations;
- Attachments - Location Map, Drawings, etc.;
- Appendix A - Field Bore/Core Log;
- Appendix B - Laboratory Test Results;
- Appendix C - Geophysical Test Results; and
- Appendix D, etc. - Photographs, miscellaneous test results and/or information as deemed necessary.

6.6.2 Checklists

As a guide to ensure that all pertinent items are considered in geotechnical reports, checklists have been prepared from FHWA's 1985 publication *Checklist and Guidelines for Review of Geotechnical Reports and Preliminary Plans and Specifications*. These checklists are presented as Forms 6.4-G, 6.4-H, 6.4-K, 6.4-L, 6.4-M, 6.4-N, 6.4-O, 6.4-T and 6.4-U. The checklists are intended to be used primarily by reviewing and approving officials. Therefore, all geotechnical project engineers and geologists preparing reports should become very familiar with the contents, concepts and procedures presented in the checklists. Forms 6.4-G and 6.4-H contain information that is generally common to all geotechnical reports. Forms 6.4-K through 6.4-U are to be used for specific items addressed in specialized geotechnical reports.

6.6.3 Standard Forms

Geotechnical forms that are common to all Federal Lands Highway Divisions have been standardized and are presented in Forms in the applicable Sections. Completed examples of the more routinely used forms are included as Exhibits.

6.7 DIVISION PROCEDURES

Reserved for Federal Lands Highway Division office use in supplementing the policy and guidelines set forth in this Chapter with appropriate Division procedures and direction.